Attachment 3
The Piceance Basin

The Piceance Coal Basin is wholly contained within the state of Colorado, and is located in the northwest corner of the state (Figure A3-1). The coalbed methane reservoirs are found in the Upper Cretaceous Mesaverde Group, which covers about 7,225 square miles and ranges in thickness from about 2,000 feet on the west to about 6,500 feet on the east side of the basin (Johnson, 1989). It is estimated that 80 to 136 trillion cubic feet of gas are contained in coal beds within the basin (Tyler et al., 1998). Total coalbed methane production was 1.2 billion cubic feet in 2000 (GTI, 2002).

3.1 Basin Geology

The Piceance is a northwest trending asymmetrical, Laramide-age basin in the Rocky Mountain foreland with gently dipping western and southwestern flanks and sharply upturned eastern flank (Figure A3-1)(Tremain and Tyler, 1997). The Douglas Creek Arch bounds the basin on the northwest, and separates it from the Uinta Coal Basin, which lies almost entirely in Utah. The Mesaverde Group is sharply upturned to near vertical along the Grand Hogback, which forms the eastern boundary of the basin and separates the basin from the White River uplift to the east. Most of the Piceance Basin's coal deposits are contained within the Iles and Williams Fork Formations of the Late Cretaceous age Mesaverde Group, which are approximately 100 to 65 million years in age (McFall et al., 1986). These formations composed of sandstone and shale, were deposited in a series of regressive marine environments (McFall et al., 1986; Johnson, 1989). It is believed that the coals were deposited in marine transitional, brackish, interdistributary marshes and freshwater deltaic swamps (Collins, 1976 in McFall et al., 1986). Figure A3-2 presents a stratigraphic section shown with a gamma ray-induction log from the Barrett 1-27 Arco Deep well (Reinecke et al., 1991). The Mesaverde Group is underlain by the marine Mancos Shale and overlain by the lower Tertiary age Fort Union and Wasatch Formations, which consist of fluvial sandstones and shales. The Mancos Shale, Fort Union and Wasatch Formations are essentially barren of coals (McFall et al., 1986). Depth to the coal bearing sediments vary from outcrops around the margins of the basin (Figure A3-1) to more than 12,000 feet in the deepest part of the basin (Tyler et al., 1996).

The major fold structure of the Piceance Basin is the Grand Hogback Monocline, formed as the White River Uplift was uplifted and thrust westward during the Laramide Orogeny in Late Cretaceous through Eocene time (McFall et al., 1986). Broad folds, such as the Crystal Creek and Rangley Syncline, trend northwest to southeast, and generally parallel to the axis of the basin (Figure A3-1). Intrusions occur throughout the southeast part of the basin, locally elevating coal ranks to as high as anthracite grade. A buried laccolith intrusion is thought to be present under a coal basin anticline along the southeast margin of the basin (Figure A3-1) where high quality coking coal was mined since the 1800’s (Collins, 1976).

Coalbed methane reservoirs occur exclusively in the Upper Cretaceous Mesaverde Group (Figure A3-2), which covers an area of approximately 7,255 square miles (Tremain and Tyler, 1997). Depths to the Mesaverde Group range from outcrop to greater than 12,000 feet along the axis of the basin (Tyler et al., 1996; Tremain and Tyler, 1997). Two-thirds of the coalbed methane occurs in coals deeper than 5,000 feet, making the Piceance Basin is one of the deepest coalbed methane areas in the United States (Quarterly Review, August 1993).

The major coalbed methane target, the Cameo-Wheeler-Fairfield coal zone (Figure A3-3), is contained within the Williams Fork Formation of the Mesaverde Group and holds approximately 80 to 136 trillion cubic feet of coalbed methane (Tyler et al., 1998). This coal zone ranges in thickness from 300 to 600 feet, and lies more than 6,000 feet below the ground surface over a large portion of the basin (Tyler et al., 1998). Individual coal seams of up to 20 to 35 feet thick can be found within the group, with net coal thickness of the Williams Fork Formation averaging 80 to 150 feet thick. In 1991 at the Grand Valley field (Figure A3-4), 23 out of 41 methane wells produced from coalbeds (Reinecke et al., 1991). However, in 1984, most wells at the Rulison field (Figure A3-4) reached their maximum depths above the Cameo coal zone, and the coalbeds were not a methane producing horizon.

Initially, it was anticipated that coalbed methane wells in the sandstones and coals of the Cameo zone would have high production rates of water. However, testing later showed that they produced very little water (Reinecke et al., 1991). Both the sandstones and coal beds are tight, poorly permeable, and are generally saturated with gas rather than water or a mixture of water and gas. Tyler et al. (1998) state that geologic and hydrologic controls need to be synergistically combined in order to achieve the highest gas production, and conclude that this synergism is absent in the hydrocarbon-overpressured part of the Piceance Basin. The dynamic flow of a hydrologic system enhances the collection of gas in traps, but in much of the Piceance Basin that flow is not present because of the overpressuring and saturation with gas.

Consequently, the conventional models for coalbed methane accumulation developed for other basins do not apply well for exploration and development in the Piceance Basin. Tyler et al. (1996) concluded, “very low permeability and extensive hydrocarbon overpressure indicate that meteoric recharge, and, hence, hydropressure, is limited to the basin margins and that long-distance migration of ground water is controlled by fault systems.” Recharge is limited along the eastern and northeastern margins of the basin because of offsetting faults, but zones of transition between hydropressure and hydrocarbon overpressure in the western part of the basin and on the flanks of the Divide Creek Anticline in the southeastern part of the basin may possess better coalbed methane potential, as indicated by the exploration targets delineated in Tyler et al. (1998) (Figure A3-5).

3.2 Basin Hydrology and USDW Identification

The Piceance Basin contains both alluvial and bedrock aquifers. Unconsolidated alluvial aquifers are the most productive aquifers in the Piceance Basin. These alluvial deposits are narrow, and thin, deposits of sand and gravel formed primarily along stream courses. The City of Meeker, Colorado is supplied by wells tapping these deposits where they are over 100 feet thick in the White River valley (Taylor, 1987).

The most important bedrock aquifers are known as the upper and lower Piceance Basin aquifer systems. These consolidated rock aquifers are lower Tertiary Eocene in age and occur within and above the large oil shale reserves. The upper and lower aquifers are separated by the Mahogany zone of the Parachute Creek Member (Figure A3-6). The Mahogany zone is a poorly permeable oil shale, which retards water movement but does not stop it. Both bedrock aquifers overlie the older Cretaceous Mesaverde Group where the coal and coalbed methane are located.

The upper aquifer system is about 700 feet thick and consists of several permeable zones in the Eocene Uinta Formation and the upper part of the Parachute Creek Member of the Eocene Green River Formation. Sub-aquifers of the Uinta Formations are silty sandstone and siltstone while those of the Parachute Creek Member of the Green River Formation are fractured dolomite marlstone. There is some primary porosity in the sandstone and the permeability of the sub-aquifers has been enhanced by natural fracturing that occurred during post-deposition deformation. Layers between the individual sub-aquifers are less permeable than the sub-aquifers themselves, but do not prevent water movement between the sub-aquifers.

The lower aquifer system is about 900 feet thick and consists of a fractured dolomitic marlstone of part of the lower Parachute Creek Member of the Green River Formation. It is semi-confined below the Mahogany Zone and above the Garden Gulch Member of the Green River Formation and a high resistivity zone just above it (USGS, 1984 and Taylor, 1987)(Figure A3-6). Fracturing during deformation of the rocks and subsequent solution enlargement owing to dissolution of soluble evaporite minerals has increased permeability of this lower aquifer system.

Ground water is recharged from snow melt on high ground from where it travels down through the upper aquifer system, the Mahogany zone, and into the lower aquifer system. The ground water then moves laterally and/or upward discharging from both the upper and lower aquifer systems into streams (Figure A3-7). The minerals nahcolite ($NaHCO_3$), dawsonite ($NaAl(OH)_2CO_3$) and halite (NaCl) are present in the ground water, and the circulation of the ground water (with these minerals in solution) has caused enlargement of the natural fractures (Taylor, 1987). Water in the lower aquifer is reported to contain several hundred milligrams per liter of chloride (Taylor, 1987).

Wells in these two bedrock aquifer systems, the upper and lower Piceance Basin aquifers, typically range in depth from 500 to 2,000 feet, and commonly produce between 2 to 500 gallons per minute of water (USGS, 1984). These Tertiary bedrock aquifers are stratigraphically separated from the base of the Cameo coal zone in the Cretaceous Mesaverde Group by from less than 1,500 feet of strata along the Douglas Creek Arch to more than 11,000 feet along the basin trough just west of the Grand Hogback (Johnson and Nuccio, 1986) (Figure A3-2).

Aquifer maps do not exist for the Piceance Basin, but water quality in the Piceance Basin is poor owing to nahcolite (sodium bicarbonate) deposits and salt beds within the basin (Graham, 2001). Only very shallow waters such as those from the surficial Green River Formation are used for drinking water (Graham, CDWR, personal communication 2001). In general, the potable water wells in the Piceance Basin extend no further than 200 feet in depth, based on well records maintained by the Colorado Division of Water Resources. At least two wells in the area are approximately 1,000 feet in depth, but they are used for stock watering. A composite water quality sample taken from 4,637 to 5,430 feet deep within the Cameo Coal Group in the Williams Fork Formation exhibited a TDS level of 15,500 mg/L (Graham, CDWR, personal communication 2001). The produced water from coalbed methane extraction in the Piceance Basin is of such low quality that it must be disposed of in evaporation ponds or re-injected into the formation from which it came or at even greater depths (Tessin, 2001).

It is unlikely that any USDWs and methane bearing coals (generally located at great depth) would coincide in this basin. The thousands of feet of stratigraphic separation between the coal gas bearing Cameo zone and the lower aquifer system in the Green River Formation should prevent any of the effects from the hydrofracturing of gas-bearing strata from reaching either the upper or the lower bedrock aquifer USDWs.

Permeability of the coal and the surrounding sandstone and shale is generally quite low except near outcrop, making the potential for these rocks to contain a USDW very small. Researchers (Reinecke et al., 1991) report that the permeability of gas bearing coal and sandstone of the Cameo zone is so low that the gas is overpressured and has forced ground water out of the zone, a condition that tends to disfavor the entrapment of methane. Tyler et al. (1998) state that high coalbed methane gas productivity requires synergistic geologic and hydrologic conditions, and that these conditions are not optimal throughout much of the Piceance basin because of the absence of dynamic ground water flow and because of low permeability of the host rocks.

The above conditions prevail in the central part of the basin, previously favored as a coalbed methane development fairway, and heavily targeted for exploration (Nowak, 1991). However, analyses by Tyler et al. (1998) suggest that a transitional zone, between the deeply buried coal and the outcrops at the boundaries of the basin, where ground water circulation may be sufficient to create more favorable trapping conditions (Figure A3-5), may be a better target area for coalbed methane production exploration. These exploration target zones could possibly have sufficient meteoric ground water circulation to meet the water quality criterion of USDWs. However, Figure A3-3 shows that the depths to coals in the targeted methane producing zones (Figure A3-5) are greater than 4,000 feet below the ground surface and therefore not likely to contain water that would meet the USDW quality criterion of 10,000 mg/L TDS. Currently, test-drilling information is insufficient to determine if this is the case. Nevertheless, due to the very low permeability, great depth, and expected poor water quality of the targeted, coalbed methane producing zones, conflicts with USDWs are considered to be of very low probability.

3.3 Coalbed Methane Production Activity

Measurements of coal permeabilities in the Piceance Basin have shown that the deep coals typical of the basin are much less permeable than coals in top-producing coalbed methane basins such as the San Juan Basin in Colorado (Quarterly Review, 1993). Consequently, operators rely on large hydraulic fractures to produce coalbed methane from the deep, low permeability coals (Quarterly Review, 1993).

Exploration for coalbed methane began in the basin during the early 1980s, but viable commercial production did not begin until 1989 (Quarterly Review, 1993). The first well to commercially produce coalbed methane from the Piceance Basin, Exxon's Vega No. 2 well in Mesa County, went off-line in 1983 (Quarterly Review, 1993). Amoco Production Company attempted multi-well coalbed methane development in the late 1980s, and finally ceased activity in 1989. Commercial production was finally achieved in 1989 in the Parachute fields operated by Barrett Resources. Barrett Resources drilled 68 wells in 1990 and had planned for 22 more in 1991 (Western Oil World, 1991). The wells targeted both coals and sandstone within the Cameo coal zone and the Mesaverde sandstones, just above the Cameo coals. Other operators soon followed suit, including Fuelco at White River dome field in the northern part of the basin (Figure A3-1), Conquest Oil Company near Barretts production in the central part of the basin, Chevron USA Inc., and many others. However, not all operators were successful in locating or producing coalbed gas. Ultimately, Barrett found the sandstones to be far more productive than the coal beds, and attempts to complete wells in the coal beds were largely abandoned.

Within the Cameo coal zone, Barret Resources typically used 3,000 to 3,500 barrels of gelled 2% potassium chloride (KCl) water with 273,000 to 437,000 pounds of sand over a maximum 450 feet of the Cameo Coal Zone to stimulate coalbed methane wells (Quarterly Review, 1993). It was shown that these hydraulic stimulations created short (100-foot), multiple fractures around the wells (Quarterly Review, August 1993). Fuel Resources Development Company used 3,000 to 10,000 barrels of gelled water and 200,000 to 1,300,000 pounds of sand to fracture their wells in the White River dome field (Quarterly Review, 1993). All but one of Conquest Oil Company's wells were hydraulically fractured with 1,500 barrels of water or cross-linked gel and 31,000 to 230,000 pounds of regular or resin-coated sand (Quarterly Review, 1993).

3.4 Summary

The Piceance Basin shows promise as a source for coalbed methane production based on the estimated 80 to 136 trillion cubic feet of gas contained within the Cameo-Wheeler-Fairfield coal zone (Tyler et al., 1998). However, overall low permeabilities as well as great depths to coal beds appear to have slowed coalbed methane development in the basin.

Hydraulic fracturing is a common practice in coalbed methane completions in this basin. The fluids used during fracturing vary from water to gelled water, with sand as a proppant. From 1,500 to more than 11,000 feet of strata separate the coals from the shallow USDWs, indicating that the potential for water quality contamination from hydraulic fracturing techniques is minimal. The only hydraulic fracturing fluid contamination pathway to the USDWs might be through faults or fractures extending between the deep coal layers and the shallow aquifers. The occurrence of these fractures and faults has not been substantiated in any of the literature examined for this investigation.

Water at depth in the Piceance Basin appears to be of poor quality, minimizing its chance of being designated as a USDW. However, research (Tyler et al., 1998) suggests that gas exploration may target marginal areas of the basin where ground water circulation may enhance gas accumulation in the coal and associated sandstones. A USDW in shallower Cretaceous rocks near the margins of the basin could be affected by hydrofracturing in the newly targeted areas, but the likelihood of the presence of a USDW in these rocks is remote.

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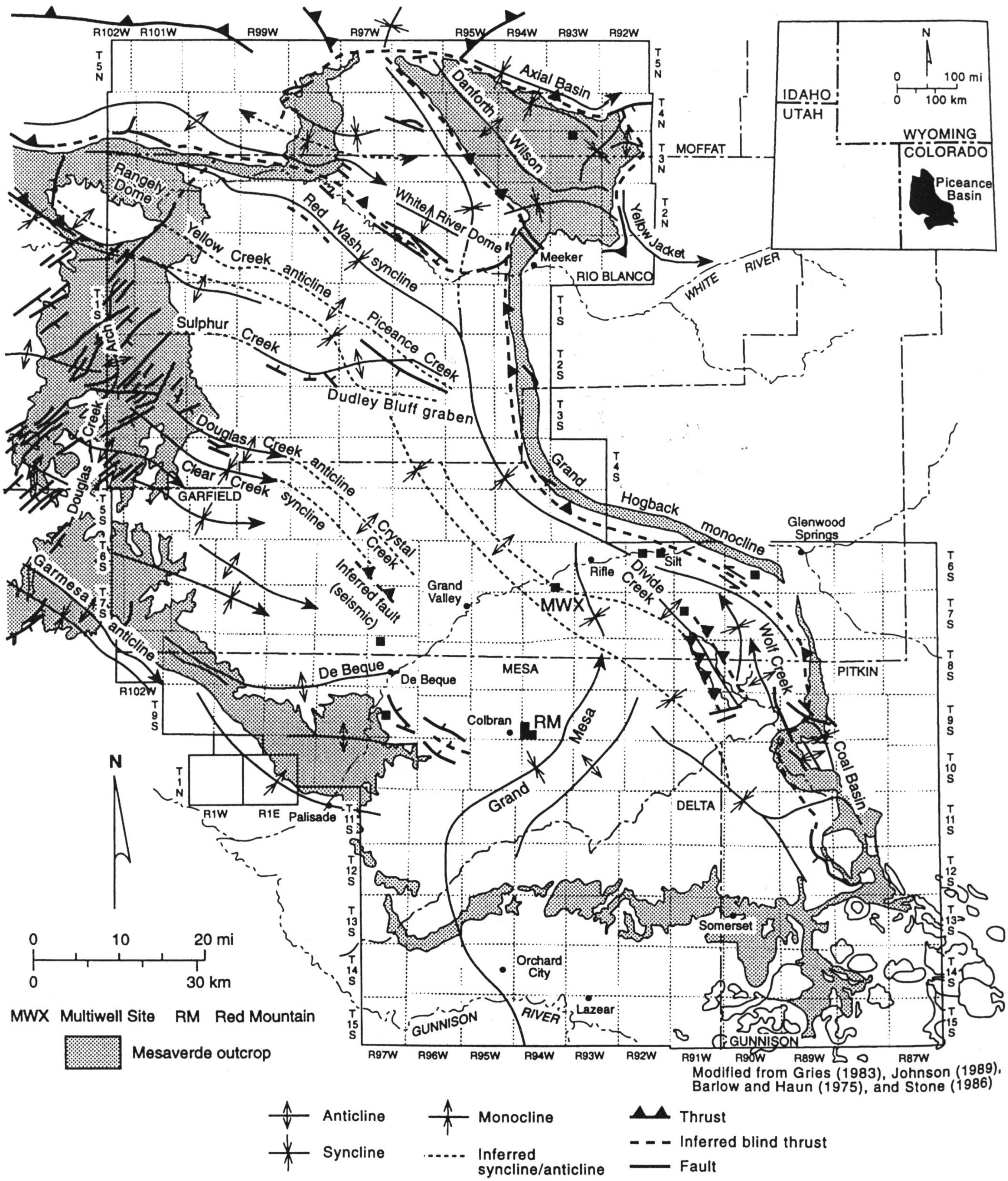
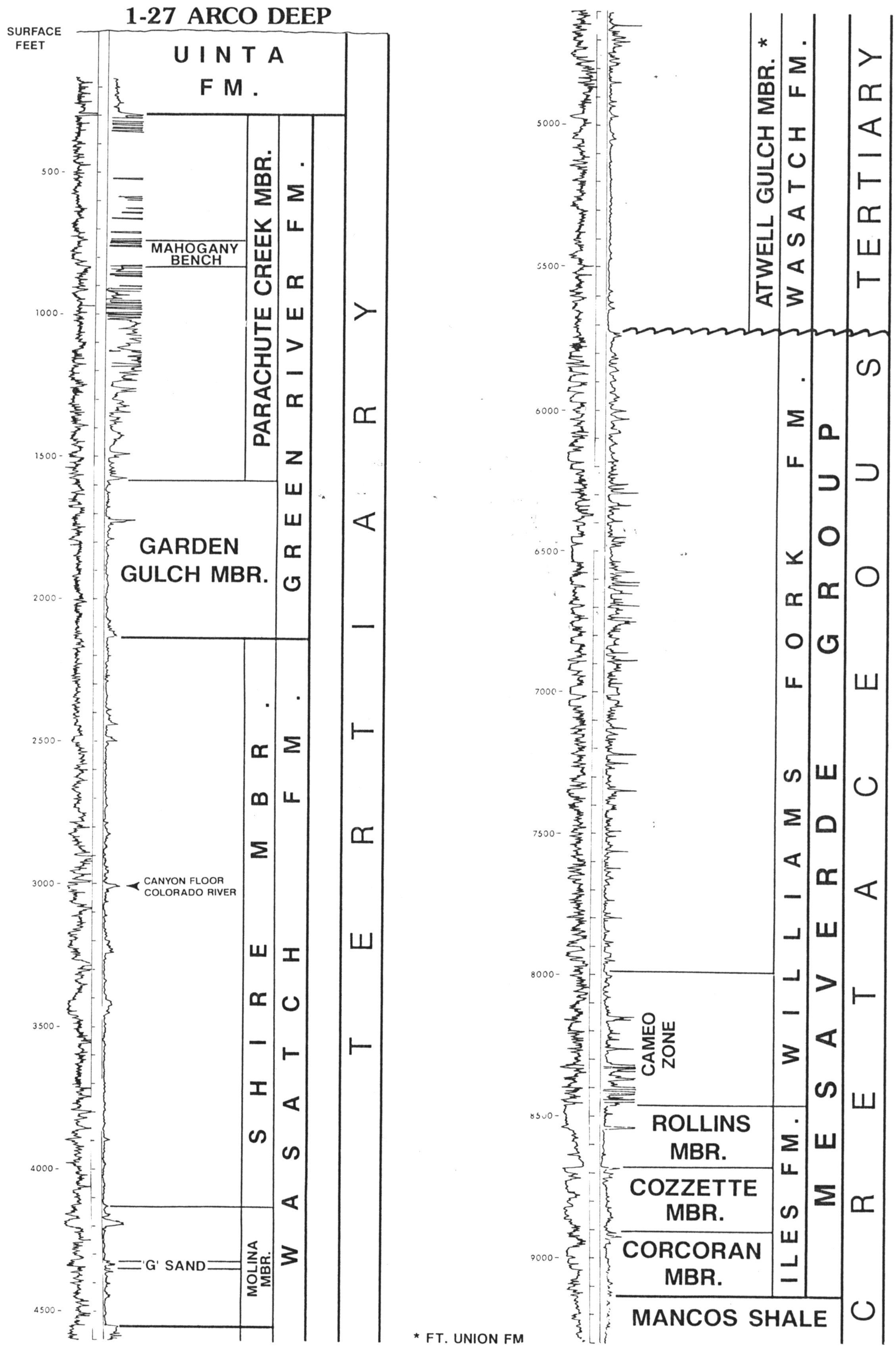


Tectonic Map of the Piceance Basin (Tremain and Tyler, 1997)

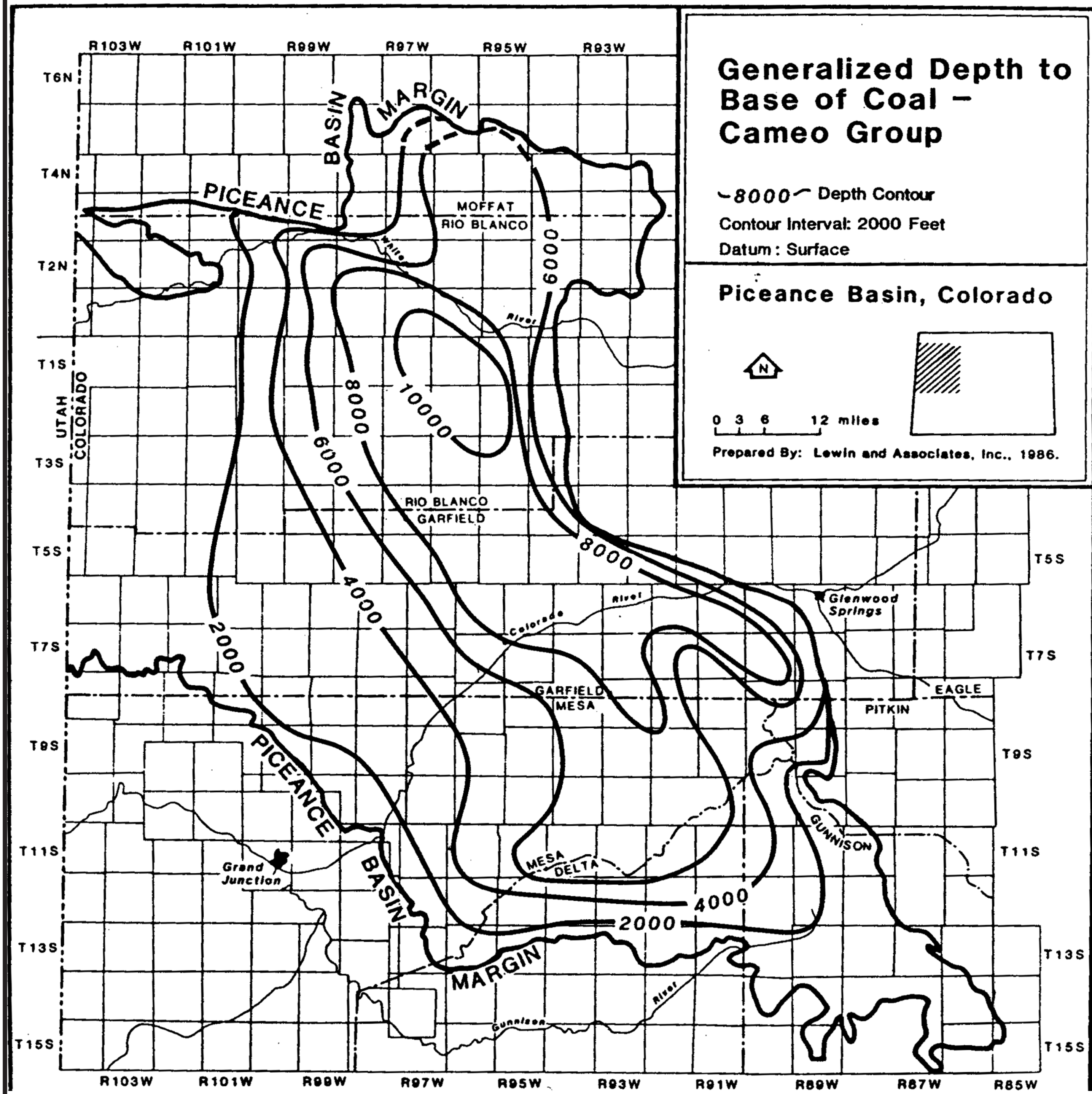
7/14/01 kk 1027-HF-Piceance-1.cdr

Figure A3-1



Stratigraphic Section of the Piceance Basin (Reinecke et al., 1991)

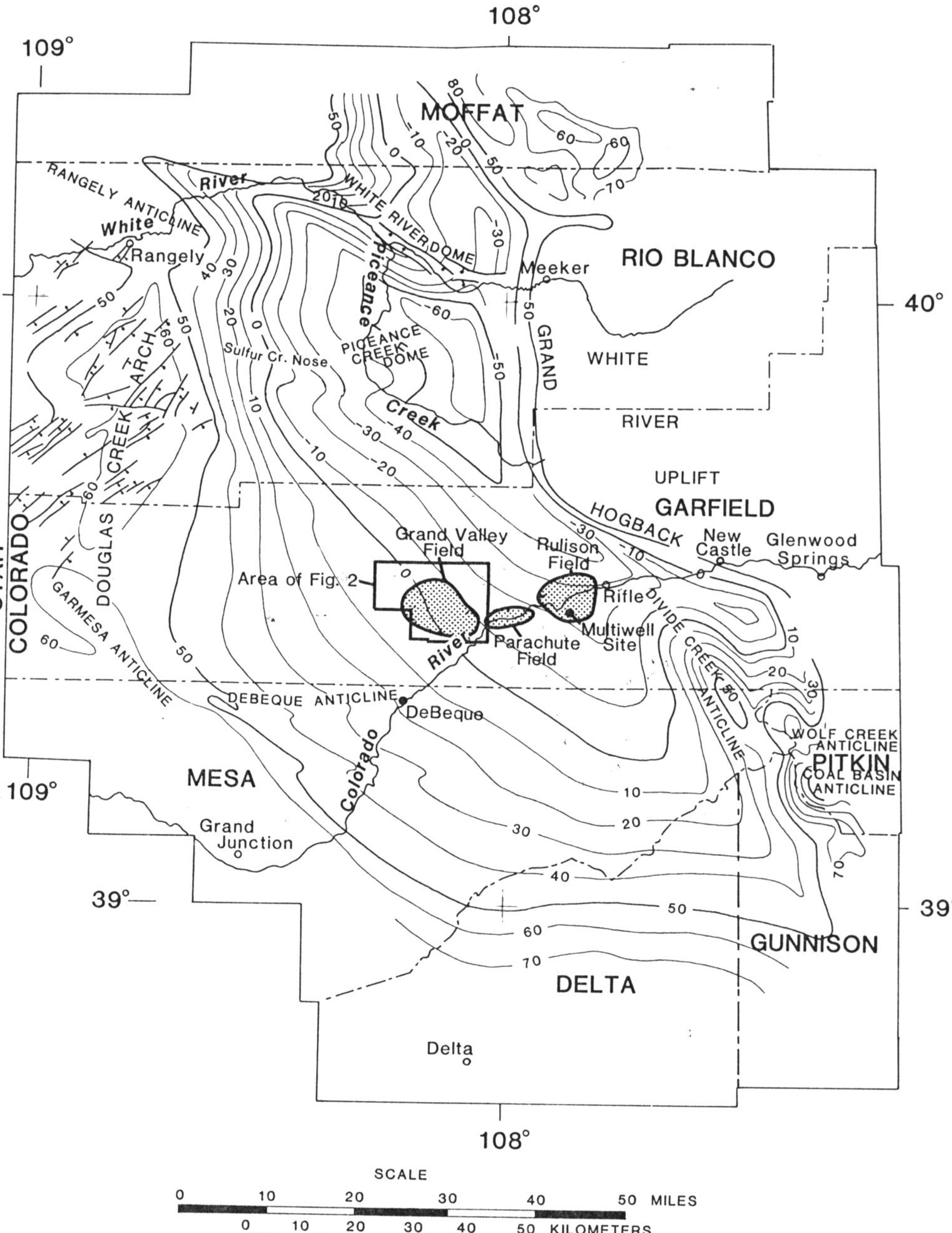
7/14/01 kk 1027-HF-Piceance-2.cdr	Figure A3-2



Generalized Depth to Base of Coal-Cameo Group (Lewin and Associates, Inc. 1986)

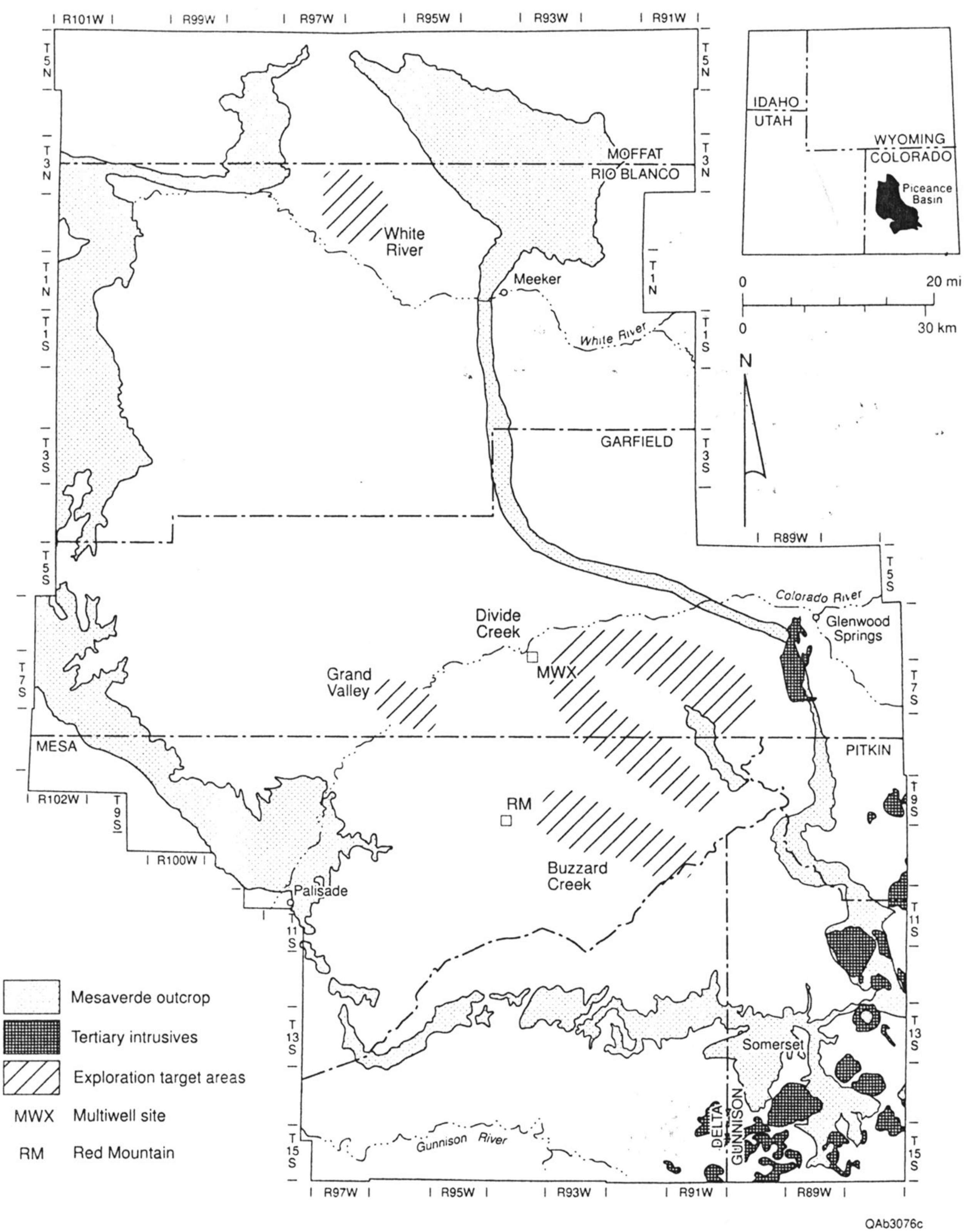
7/14/01 kk 1027-HF-Piceance-3.cdr

Figure A3-3



Locations of Gas Fields (Reinecke et al., 1991)

7/14/01 kk 1027-HF-Piceance-4.cdr	Figure A3-4



Exploration Target Areas, Piceance Basin (Tyler et al., 1998)

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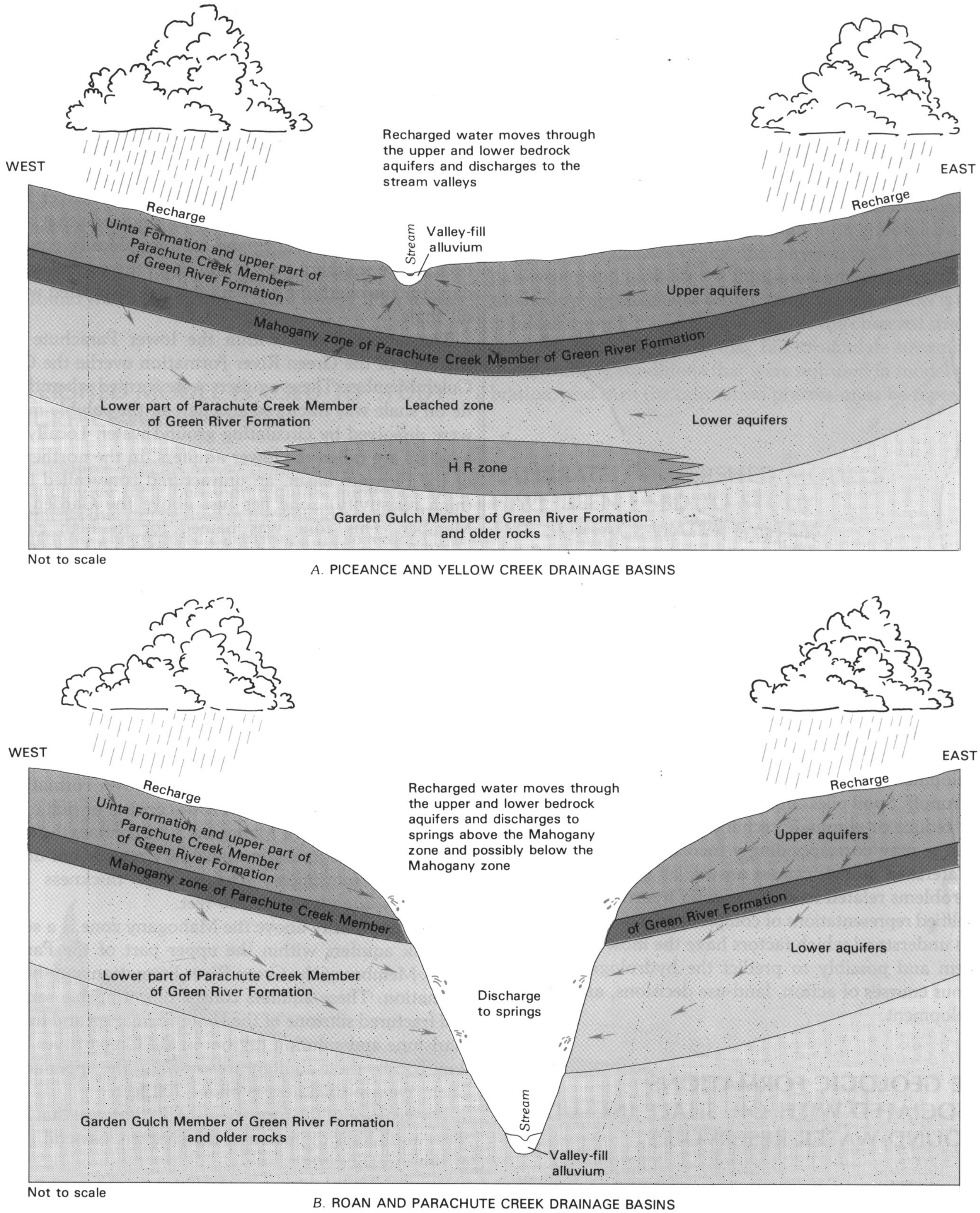
Figure A3-5

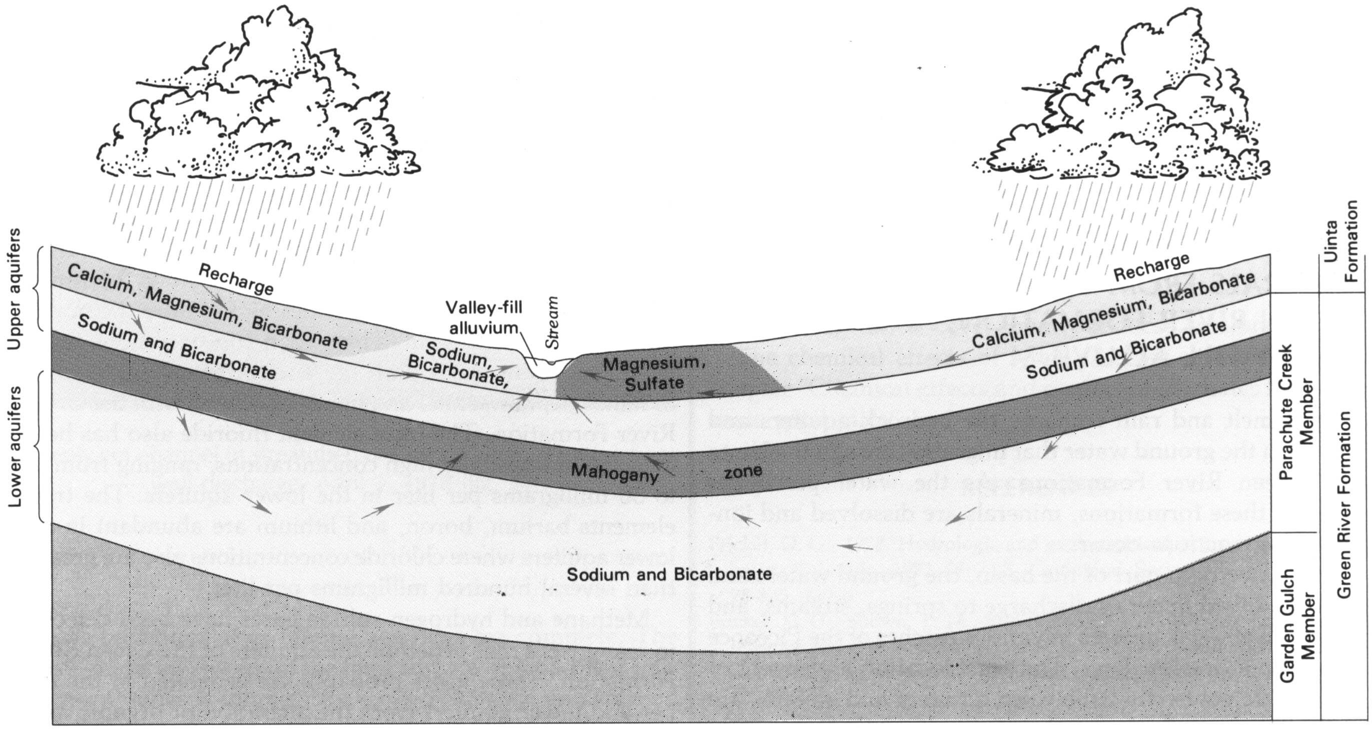


Diagrammatic East-West Sections of Hydrologic System (Taylor, 1987)

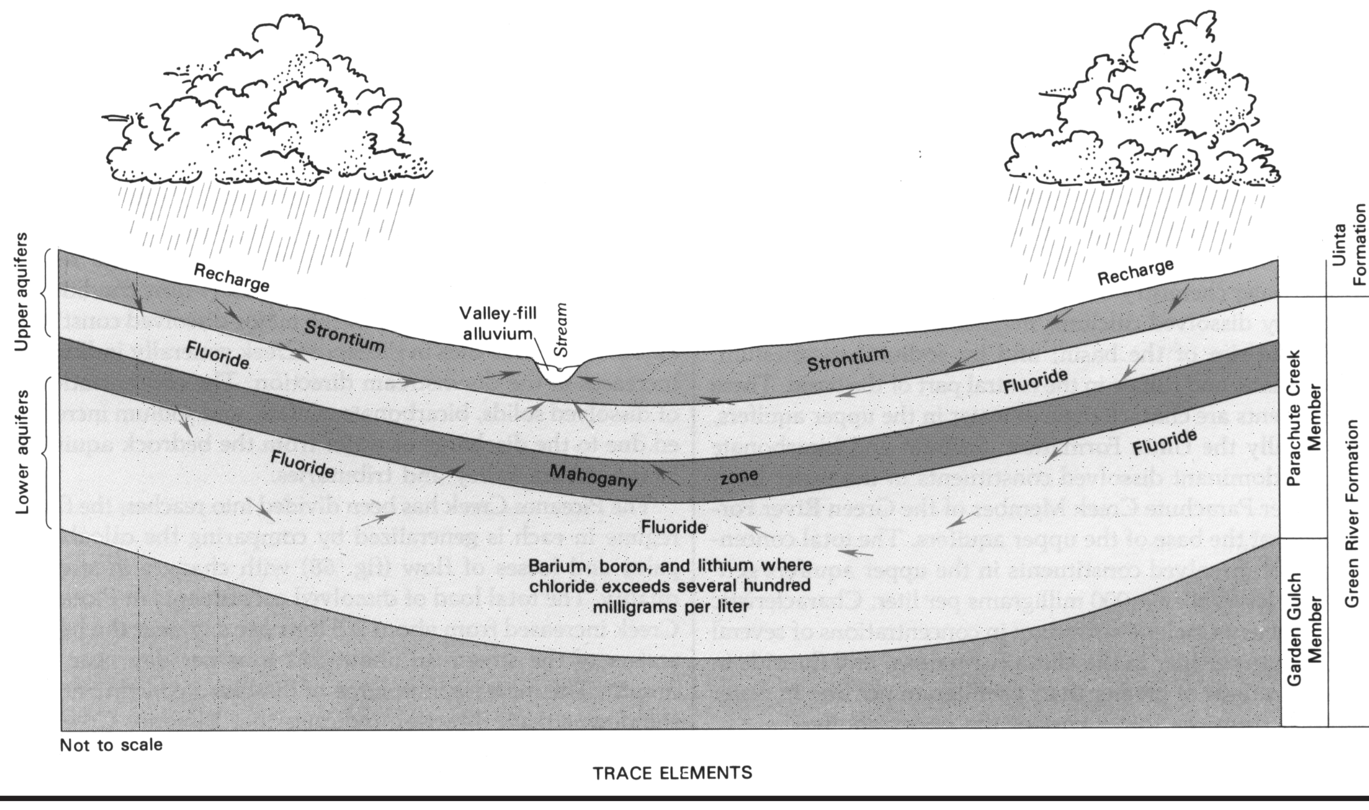
7/14/01 kk 1027-HF-Piceance-6.cdr

Figure A3-6

OIL SHALE, WATER RESOURCES, VALUABLE MINERALS, PICEANCE BASIN, COLO.



MAJOR IONS



TRACE ELEMENTS

Dominant Chemical Constituents in the Two Major Bedrock Aquifers (Taylor, 1987)

7/14/01 kk 1027-HF-Piceance-7.cdr	Figure A3-7